S
551.5
H2SFP
1979

MONTANA AIR POLLUTION STUDY

METEOROLOGICAL SUMMARY

Preliminary Report

by

J. W. Gelhaus, Project Manager
W. Campbell
S. Harner
M. Machler
T. Middlemist
A. L. Zimmerman

and

Michael D. Roach, Chief

STATE DOCUMENTS COLLECTION

DEC 03 2003

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA MONTANA 59620

AIR QUALITY BUREAU

ENVIRONMENTAL SCIENCES DIVISION
MONTANA DEPARTMENT OF HEALTH AND ENVIRONMENTAL SCIENCES
HELENA, MONTANA 59601

MARCH, 1979

MONTANA STATE LIBRARY
3 0864 1002 3752 1

PREFACE

This document is one of a series of reports on the Montana Air Pollution Study (MAPS), a project being conducted by the Department of Health and Environmental Sciences. Developed in response to House Bill 250, enacted by the Forty-fifth Montana Legislature, the MAPS project is an ambient air monitoring and health effects study intended to expand knowledge of air pollution in the state and to investigate the relationship between air pollution and the health of Montana's residents.*

This specific report is intended as a preliminary summary of the meteorological studies undertaken in MAPS and other related studies. Data in this report are from MAPS, the Air Quality Bureau's Anaconda Upper Air Study and Flathead Environmental Study, the Anaconda Company, Hoerner-Waldorf Corporation, the National Weather Service, and the Montana Energy Research and Development Institute.

The MAPS activities were initiated in July, 1977; however delivery of equipment and time required for installation caused many of the meteorological studies to be started after May, 1978. This report, therefore, covers the period from May through December, 1978, for most study areas. A final report covering all meteorological data collected will be released in June, 1979.

---

*The approach and methodology of MAPS is discussed in more detail in the MAPS 1977-1979 Approach and Methodology Report dated December, 1978; Air Quality Bureau, Montana Department of Health and Environmental Sciences.

EXECUTIVE SUMMARY

This report provides preliminary summaries of data on surface and upper air meteorology as related to air pollution potential. The Montana Air Pollution Study established major met monitoring sites in Billings, Butte and Missoula; also included is similar data gathered in Anaconda and Columbia Falls under other, coordinated Bureau projects.

Primary parameters being measured are surface and upper level wind speed and direction; inversion height, thickness, and strength; stability; and visibility. Various other meteorological parameters are also being measured or gathered from other data sources such as the National Weather Service, companies, or institutions. The data is currently being reduced to computer format and analyzed by meteorologists.

This preliminary report is a brief review of the sampling program and the initial results being obtained. The sampling period covered is May 1978 through December 1978. A more in-depth analysis will be made of all the meteorological data being collected before the final report is published in June 1979.

Data on the upper level winds in the various study areas has already revealed predominant wind patterns for the various months sampled. Inversion data from two measurement methods is being summarized, and comparisons are being made as to frequency of occurrence of various inversion parameters such as thickness, height, intensity,

and duration. Stability data derived from acoustic radar data, cloud data, and wind speed is also currently being tabulated continuously in two-hour periods. Finally data on atmospheric turbidity is being correlated with various air quality and meteorology parameters. Additional data on surface wind patterns, pressure, solar radiation, dewpoint, temperature, etc., are not available at this time but are being sampled continuously and will be analyzed prior to the final report.

TABLE OF CONTENTS

		Page
EXECUTIVE SUMMARY		i
I.	INTRODUCTION	1
II.	STUDY DESIGN AND METHODLOGY	3
	MEASUREMENT METHODS	3
	SITE DESCRIPTIONS	7
III.	RESULTS AND ANALYSIS	19
	UPPER LEVEL WINDS	19
	INVERSION STUDY	24
	STABILITY	38
	TURBIDITY	43
	OTHER METEOROLOGICAL PARAMETERS MEASURED	50
IV.	SUMMARY	51
REFERENCES		52

TABLES

No.	Description	Page
1	Summary of Meteorological Monitoring Network	6
2	Lift Rates for Various Balloons	8
3	Ambient Air Network (Anaconda Company)	9
4	Holzworth Lapse Rate Categories (Modified)	27
5	Inversion Formation and Lifting Time	36
6	Inversion Formation and Lifting Time (corrected)	37
7	Acoustic Radar Analysis	40
8	Stability Classification From Acoustic Radar Charts	42
9	Atmospheric Turbidity Data	45

I. INTRODUCTION

Meteorological conditions have a major effect on the frequency and severity of air pollution concentrations in the air. The ability of the lower atmosphere to disperse, dilute and mix pollutants released into it can vary immensely with meteorological fluctuations from day to day, week to week, and season to season. These meteorological variations are a major influence on air pollution concentrations. Therefore, it is essential that such meteorological variations be measured and compared with the associated changes in pollution to determine their relationship. Only through the analysis of air quality and meteorology together is it possible to describe, anticipate, or predict accurately the atmospheric changes that may affect pollution concentrations.

The lower atmosphere air movement patterns typical of the mountainous terrain of the western part of the country are far more erratic than those over flat terrain. Valley-mountain terrain causes air movement patterns that frequently vary greatly over short distances. Several Montana cities are located in valleys surrounded by mountains. In these areas, the escape of pollutants from the valley "bowl" is very limited under certain meteorological conditions, such as low winds and temperature inversions.

The meteorological network established in Montana in the past, primarily by the National Weather Service, has provided a basis for

describing or forecasting the general weather conditions that apply to large areas, usually the size of several counties. The major forecast emphasis has been on temperature and precipitation and the occurrence of storms accompanied by high winds, blizzards, flooding, and other such phenomena. This data network is not adequate to provide data needed to identify and understand local meteorological effects on air pollution.

In the planning of MAPS, several technical advisory committees were established to review the data needs and make recommendations on the project design. The MAPS Advisory Committee for Meteorology/ Modeling reviewed the present data sources in the study areas and compared these sources with the data needs. The MAPS staff, following the recommendations of the advisory committee, implemented a network of meteorological monitors to provide data needed to identify and understand the local meteorological effects on air pollution.

II. STUDY DESIGN AND METHODOLOGY

Following is a general description of the MAPS meteorological instrumentation and methods which provides data essential in evaluating the inter-relationship between meteorology and air quality.

Measurement Methods

Temperature difference at different heights above ground surface is related to vertical air motion in the atmosphere. Such vertical movements are less rapid, more random, and are sustained over much shorter periods than horizontal winds. However, this vertical motion is a crucial aspect of the atmosphere's ability to mix and dilute pollutants. In effect, vertical motions determine how much of the atmosphere's depth will be available to disperse pollution. Since this mixing depth varies more than the vertical wind speed, it is often the most important factor in determining the air's capacity to disperse pollution.

As part of its study effort on atmospheric conditions, the MAPS project provided an acoustic radar for the Billings area. Acoustic radars were also available through other studies for the Kalispell and Anaconda areas. Use of acoustic radars owned by cooperating agencies made data available in the Missoula (U.S.D.A. Forest Service) and Butte (Montana Energy Research and Development Institute) areas. This instrument is used in determining vertical temperature change

characteristics above the ground surface and is useful for finding how stable (stagnant) or unstable (rapidly changing and moving air currents) the atmosphere is at any given time. Acoustic radar provides a continuous record of atmospheric temperature fluctuations and the resulting small-scale air turbulence in the lower 1000 meters. The device sends a sound pulse vertically into the air, where layers of various temperature differences or wind fluctations reflect it back to the transmitter receiver, where the returned sound pulse is recorded.

A continuous record of wind speed and direction is essential to understand and describe the drift and dispersion of pollutants released at or near the ground surface. Monitors must be placed at sites selected to allow determination of wind variables caused by local topography. "Primary" wind monitoring sites are those placed at points where pollutants are being measured and monitored. "Secondary sites" have been established in each study area to measure the wind at representative points where the terrain causes marked variation. Anemometers are installed on 10-meter towers at most of the wind recording sites.

Lighter-than-air balloons with a known ascent rate are used to sample meteorological conditions in the atmosphere. The network of balloon soundings operated by the National Weather Service provides the major contribution to its forecast system. However, this network grid is insufficient for use in predicting local variations in air circulation. As an example, the network for Montana consists of two balloon sounding stations, at Great Falls and Glasgow. Closest adjacent soundings are at Spokane, Washington; Boise, Idaho; Lander, Wyoming; and Rapid City, South Dakota.

The MAPS program has established balloon sounding stations at Butte, Missoula and Billings. Other studies have provided balloon soundings from the Anaconda and Kalispell areas. Soundings to determine wind speed and direction and the temperature profile for the lower several thousand feet of the atmosphere are taken shortly after sunrise (when atmospheric motion is normally at a minimum) and in the afternoon (when atmospheric motion is normally at a maximum). Helium-filled balloons are tracked by theodolites and positions are recorded at thirty-second intervals. A small and inexpensive temperature thermistor and battery operated radio transmitter sent aloft provide a continuous record of temperature on a ground-based recorder as the balloon rises.

The influence of the sun's radiation upon the turbulence of the atmosphere and upon certain photochemical reactions makes measurements of radiation important in air pollution studies. In addition, the amount of incoming solar radiation may be reduced by particulate pollution in the atmosphere. Therefore, it is often desirable to compare solar radiation levels between urban and non-urban stations.

Fine particulates, dust, and various aerosols produce haze and reduce visibility, causing "turbidity" in the atmosphere. Turbidity is measured as the amount of light that can penetrate a cloud-free atmosphere. Turbidity measurements are made with a relatively simple hand-held instrument called a sun photometer. Readings are taken under cloudless skies when the sun is shining, and these readings relfect the degree to which incoming radiation is reduced by air pollution.

TABLE 1

SUMMARY OF METEOROLOGICAL MONITORING NETWORK

Parameter	Anaconda	Billings	Butte	Missoula
Wind speed and direction	Lincoln School Highway 48 Junction Anconda Co. (6)	Central Park NWS-Airport Horseshoe Hills	Hebgen Park FAA-Airport "Alpine West" MHD facility	Lions Park Steigler Site Olafson Site University Park Hoerner-Waldorf NWS-Airport
Solar radiation	Lincoln School	Central Park	Hebgen Park MHD facility	Lions Park
Turbidity	Lincoln School	Yellowstone County APC Office	Hebgen Park	Nursing School
Temperature	Lincoln School Anaconda Co. (2)	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Relative humidity or dewpoint	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Barometric pressure	Lincoln School Anaconda Co.	Central Park NWS-Airport	Hebgen Park FAA-Airport MHD facility	Lions Park NWS-Airport
Stability and inversion height	Highway 48 Junction	Vo-Tech site	MHD facility Airport site	USFS Fire Lab
Upper level wind	Highway 48 Junction	Vo-Tech site	Airport site	USFS Fire Lab
Precipitation	Anaconda Co.	NWS-Airport	FAA-Airport	NWS-Airport
Cloud cover and height		NWS-Airport	FAA-Airport	NWS-Airport
Visibility		NWS-Airport	Hebgen Park FAA-Airport	Lions Park NWS-Airport

Smaller Study Areas

East Helena: ASARCO - complete set of above
Colstrip-Hardin: Complete set of above
Columbia Falls: Compete set of above

Site Descriptions

The following discussion describes the various sites used in the MAPS and other studies. A summary listing of the sites and the meteorological parameters obtained at each site is given in Table 1.

Anaconda

The study area is situated at the southwest corner of a large mountain-highland (Deer Lodge Valley). The valley provides the headwaters for the Clark Fork River. The area experiences frequent nocturnal and climatic temperature inversions. It also experiences unique wind conditions due to the terrain's influence on predominant winds and the various mesoscale drainage systems.

Highway Junction Site

The Highway Junction site is located two miles northeast of the Anaconda Company smelter works in a relatively obstruction-free area. The site provides a continuous record of wind speed and wind direction.

An acoustic radar system is used to continuously monitor and record atmospheric stability. The system also provides a means to classify inversion information: breakup times, inversion base and ceiling heights, inversion type, mixing heights, and climatic events.

Upper level wind speed and direction measurements are made through the use of a single theodolite/pilot balloon tracking system. Pilot balloons are launched Monday through Friday, twice a day (one-half hour after sunrise and 1400 Mountain Standard Time (MST) weather permitting). The pilot balloons are precalibrated for a constant ascent rate. (See Table 2.)

TABLE 2

LIFT RATES FOR VARIOUS BALLOONS*

Weight No.	Weight (g)	Lift Rate (m/sec)+
1	72.0	2.75
2	33.9	1.78
3	15.0	1.28
4	5.7	0.78

*rates apply to Weather Measure 30g balloons only
+Reference Super (1972)

Lincoln School Site

The Lincoln School site is located two miles northwest of the smelter in Anaconda. It is situated in the northwest corner of the Lincoln School playground. The site contains systems to continuously record surface wind speed, wind direction, temperature, dewpoint, solar radiation, visual range and pressure.

Anaconda Company Sites

A description of sites and parameters of the Anaconda Company ambient air network is presented in Table 3. This system provides surface meteorological data from six stations at various locations in the area. All data is put into The Anaconda Company central computer for processing and printout. The data is furnished to the Air Quality Bureau in Helena.

Billings

The study area is the Yellowstone River Valley, located in southcentral Montana. The valley, elevation 3100-3600 feet MSL, is situated on the border line area between the Great Plains and the Rocky Mountains.

TABLE 3

AMBIENT AIR NETWORK (ANACONDA COMPANY)

Station	Location with respect to smelter stack	Elevation	Meteorological parameters observed
1	2 miles NW	5332	wind speed wind direction
2	3.5 miles ENE	5010	wind speed wind direction temperature relative humidity pressure precipitation
4	2 miles SW	5515	wind speed wind direction
5	0.75 miles SSW	6379	wind speed wind direction temperature
6	2 miles W	7200	wind speed wind direction temperature
7	1.25 miles NNW	5213	wind speed wind direction

Distance and directional values are approximates

Central Park Site

The Central Park site is located one mile west of downtown Billings. The site is equipped to continuously monitor: surface wind speed, wind direction, temperature, dewpoint, solar radiation, pressure and visual range.

Vo-Tech Site

Upper level wind speed and wind direction measurements are made through the use of a single theodolite/pilot balloon tracking system at the Vocational, Technical and Career Placement Center (Vo-Tech) west of Billings. Located to the north and east of the Vo-Tech Center is a sparse residential area and to the south and west an agricultural area.

Pilot balloons are released Monday, Wednesday and Friday, twice a day (one-half hour after sunrise and 1400 MST), weather permitting. The pilot balloons are precalibrated for a constant ascent rate(s). (See Table 2.) Temperature sondes are attached to the pilot balloons to obtain a continuous trace of atmospheric temperature.

The site also provides a continuous record of atmospheric stability and inversions by means of an acoustic radar system.

National Weather Service

Obtained from the National Climatic Center, Asheville, N.C., are the surface observations for the Billings National Weather Service (NWS) station. The Billings NWS station, Logan Field International Airport, lies atop the rimrocks to the north of the city. The data includes: wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation, and cloud cover.

Laurel Farm Site

Surface wind speed and wind direction are recorded continuously at a site one-half mile east of the Laurel Cenex Refinery, and just south of Interstate 90. The site is relatively obstruction free.

Yellowstone County Air Pollution Control Office

Turbidity measurements, using a sun photometer, are taken Monday through Friday. when the sky is cloudless, at 0900, 1200, 1500 MST. The measurements are taken at the Yellowstone County Air Pollution Control Office, Second Avenue North in downtown Billings.

Butte

The study area is a relatively small (10 x 5 miles) mountain-highland valley in southwestern Montana. It is situated at an approximate elevation of 5500 feet, adjacent (west of) the Continental Divide. The area experiences frequent inversion conditions especially long-lived and intense during the winter season. Due to its high elevation and the cold air pooling effect of the valley, it is also noted as an especially cold area.

Hebgen Park Site

The Hebgen Park site is located in central Butte on First Street, two miles south-southwest of the Berkley open pit mine. The city of Butte lies at the northern perimeter of the valley. Surface wind data is collected continuously by an electrically powered wind system located atop the site's thirty foot tower. The system provides wind speed and wind direction output via a recorder housed inside the trailer.

Upper level wind measurements are made through the use of a single theodolite/pilot balloon tracking system. Pilot balloons are launched

Monday through Friday, twice a day (one-half hour after sunrise and 1400 MST), weather permitting. The pilot balloons are precalibrated for a constant ascent rate (see table 2).

Butte Airport Site

The Butte Airport site is located at the south end of the Silver Bow County Airport's garage complex. The airport is located approximately in the center of the valley flat. The site is equipped to measure upper level wind speed, wind direction as the Hebgen Park Site.

Temperature sondes are attached to the pilot balloons at the Airport site to obtain a continuous trace of atmospheric temperature.

Federal Aviation Administration

The airport is also the site for the Federal Aviation Administration Flight Service Center. The surface observations taken are: wind speed, wind direction, temperature, dewpoint temperature, precipitation, and cloud cover. Copies of the daily data are supplied to the Air Quality Bureau and are reduced to a computer format similar to the National Weather Service (NWS) Climatological cards received from Asheville, NC for Missoula, Billings and Kalispell.

KXLF Television

KXLF television is providing temperature data from their translator station located on the eastern perimeter of the valley, 2900 feet above the valley floor. This data is used for temperature lapse rate calculations.

MERDI

The Montana Energy Research and Development Institute (MERDI) is providing meteorological data. Such data dates back to February 1978.

The data is collected from two sites, the Permanent Meteorological Station and the Paxson Station; both are located at the southern end of the valley. The Permanent Meteorological Station includes a 40 meter (130 foot) tower which provides temperature at 10 and 40 meters (for lapse rate purposes), wind speed, wind direction and standard deviation at 10 and 40 meters, dewpoint temperature at 10 meters, and vertical sigma at 40 meters. The station also provides solar radiation, precipitation, pressure, atmospheric stability and inversion information (by means of an acoustic radar system).

The Paxson Station provides surface temperature, dewpoint, wind speed, wind direction, precipitation, pressure and solar radiation.

Butte-Silver Bow County Health Department

Turbidity measurements, using a sun photometer, are taken Monday through Friday, when the sky is cloudless, at 0900, 1200, 1500 MST. The measurements are taken in uptown Butte, at the Butte-Silver Bow County Health Department.

Columbia Falls/Kalispell

The study area is the Flathead Valley, approximately 40 miles west of the Continental Divide. The area's climate is affected greatly by its close proximity to Flathead Lake.

Glacier Park International Airport Site

Upper level wind and temperature measurements are made at Glacier Park International Airport, approximately eight miles north-northwest of Kalispell.

The wind measurements are made with a single theodolite/pilot balloon tracking system. The pilot balloons are released Monday,

Wednesday and Friday, twice a day (one-half hour after sunrise and 1400 MST), weather permitting. The pilot balloons are precalibrated for a constant ascent rate(s) (see table 2).

Temperature sondes attached to the pilot balloons obtain a continuous trace of atmopsheric temperature.

Atmospheric stability and inversion information are also recorded continuously with an acoustic radar system.

The site is also equipped to record continuously: surface wind speed, wind direction, temperature, dewpoint temperature, pressure and visual range.

National Weather Service

Surface meteorological data is obtained from the Kalispell National Weather Service (NWS) station at Glacier International Park Airport. The data is obtained on computer punch cards from the National Climatic Center, Asheville, N.C. The data consists of: wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation, and cloud cover.

The Kalispell NWS station also provides a breakdown of hourly visibility into quadrants during daylight hours.

Polebridge Site

Surface wind speed, wind direction and temperature are measured continuously near the Polebridge Ranger Station. Due to obstructions, the equipment was moved recently two miles north of the Ranger Station to Big Prairie.

Polson Site

Surface wind speed, wind direction, temperature, and solar

radiation are recorded continuously at the Big Sky Stables in Polson. The site is relatively obstruction free.

Water Supply

At a site one mile north of the Anaconda Aluminum Plant in Columbia Falls, surface wind speed, wind direction, temperature and solar radiation are recorded continuously.

Campbell Site

Turbidity measurements, using a sun photometer, are taken Monday through Friday, when the sky is cloudless at 0900, 1200 and 1500 MST. The measurements are taken in the northwest residential area of Columbia Falls, at the William Campbell home.

Missoula

The study area is the "Missoula Valley." This valley consists of a portion of the Bitterroot Valley to the north, and the Clark Fork Valley extending from Missoula to 20 miles to the west-northwest. The valley is shielded by the Continental Divide 60-80 miles east and the Bitterroot Range 20 miles southwest, resulting in a semiarid climate. The area experiences frequent climatic temperature inversions in the fall and winter seasons.

Lion's Park Site

The Lion's Park site is located in urban southeast Missoula. The equipment trailer is located in the northeast corner of the park. The park occupies approximately one square city block and is bordered to the north and west by commercial areas and to the south and east by residential areas.

The site is equipped to continuously monitor: surface wind speed, wind direction, temperature, dewpoint temperature, solar radiation, pressure, and visual range.

Upper level wind speed and direction measurements are made through the use of a single theodolite/pilot balloon tracking system. The balloons are precalibrated for a constant ascent rate (see table 2). The pilot balloons are released Monday, Wednesday, and Friday, twice a day (one-half hour after sunrise and 1400 MST), weather permitting.

National Weather Service

Surface meteorological data is also obtained from the National Climatic Center in Asheville, N.C. The data is obtained on computer cards, for the Missoula National Weather Service (NWS) Station, located at Johnson Bell Field, approximately six miles west of downtown Missoula. The data consists of: wind speed, wind direction, temperature, dewpoint temperature, pressure, solar radiation, precipitation and cloud cover.

The Missoula NWS station is also providing a breakdown of hourly visibility into quadrants during daylight hours.

Olofson Site

Surface wind speed and wind direction are measured continuously at the Clifford Olofson site. The site is located on Bitterroot Road (Highway 93) approximately two miles southwest of the Missoula city limits, near the mouth of the Bitterroot Valley.

Stiegler Site

Surface wind speed and wind direction are measured continuously at the Bruce Stiegler site. The site is located in the Grass Valley

Farms area, approximately seven miles west-northwest of Missoula.

University Site

The U. of M. site is located on the property of the University of Montana. The equipment is in the northeastern most corner of the Physical Plant Complex. The equipment is bordered by the Clark Fork River to the north and experiences extreme wind conditions from the mouth of the Hellgate Canyon to the east. The site is equipped to continuously monitor surface wind speed and wind direction.

Hoerner-Waldorf #1 Site

The Hoerner-Waldorf Company is providing surface wind speed and wind direction data to the Air Quality Bureau in Helena. The data is obtained from the Hoerner-Waldorf site #1, located 3/4 mile southwest of the main Hoerner-Waldorf complex.

TV Mountain Site

KECI Television is providing temperature data from its transmitter station located on TV Mountain, approximately 7000 feet above the valley floor. The site is ten miles north of Missoula. The data is used for lapse rate calculations.

MAPS Office

Turbidity measurements, using a sun photometer, are taken Monday through Friday, when the sky is cloudless, at 0900, 1200, 1500 MST. The measurements are taken by study staff at the St. Patrick School of Nursing. The area is mostly commercial, and located approximately 1/2 mile west of downtown Missoula.

United States Forest Service Site

Upper level wind and temperature measurements are made at the

Northern Forest Fire Laboratory, approximately seven miles northwest of the City. A monitoring trailer (on loan from the U. S. Forest Service) is situated in an open field 1/2 mile west of the main building.

The measurements are made through the use of a single theodolite/pilot balloon tracking system. The pilot balloons are released Monday, Wednesday, and Friday, twice a day (one-half hour after sunrise and 1400 MST), weather permitting. The pilot balloons are precalibrated for constant ascent rate(s) (see table 2).

Temperature sondes are attached to the pilot balloons to obtain a continuous trace of atmospheric temperature.

An acoustic radar system is used to continuously record atmospheric stability and inversion information.

III. RESULTS AND ANALYSIS

Upper Level Winds

Wind is probably the most significant meteorological phenomena affecting air pollution levels. Wind direction determines where air pollution will be carried, while wind speed determines how fast air pollution will be carried away. Surface wind is most often noticed in the normal course of life. However, wind at various levels above the ground is also important in determining ground level pollution concentrations. Wind is most significant in breaking up inversions with air movement. Wind direction may differ at different heights. A smokestack plume may be carried away from a city by winds near the surface. only to be returned to the vicinity by higher level winds. Winds also vary in strength and direction at different times of day or time of year, especially in mountainous areas. Temperature differences caused by uneven heating or cooling of valley walls cause the air to move up a mountain during the heat of the day and down a mountain during the night.

MAPS measured upper level winds in three cities--Billings, Butte and Missoula. Data on the upper level winds were also obtained from Kalispell and Anaconda. The following discussion briefly reviews the data obtained from the various upper air measurement sites from May through December, 1978. A more in-depth analysis of the data will be available in the final MAPS meteorological report expected to be published June, 1979

Butte Area

Surface and upper air wind programs are operated at two sites within the Butte study area. This report will review wind data from only the Butte Airport Site (located in the center of the valley), because the other site (Hebgen Park) has not been in operation long enough to provide an adequate data base. Future reports will review wind data from both sites and provide comparisons.

The area has two local surface drainage wind systems, one to the south and one to the north. The surface winds are most prevalent from the SSE-SSW in the mornings, shifting to the WSW-WNW or NNW-NNE in the afternoons. During November and December the winds tend to retain their southerly direction even in the afternoons. A comparison of seasonal wind variations (summer vs. autumn) indicates a small addition of a more westerly component to the morning wind measurements in the autumn but little change in the afternoon measurements. Calm conditions were experienced only in November. Average wind speeds vary some from month to month, with the highest winds occurring in the summer months, particularly in the afternoons. The highest average winds were from WSW-WNW in the afternoons. The lightest occurred in the NE quadrant.

Review of the wind distribution aloft over Butte indicates that the predominant wind direction is different at different heights in both morning and afternoon measurements. Winds aloft during the morning are more westerly. Above 500 meters the predominant winds are from the WSW-WNW, especially from September to December. Winds aloft during the afternoon are similar, with the predominant winds from the SW-WNW in the higher levels. Overall, the westerly influence becomes more

predominant with increase in height. As expected, the average wind speeds increase with altitude but the change is very gradual up to 500 meters, after which it becomes most pronounced, especially from September to December. The highest average wind speeds occur in the west quadrant, with the lowest occurring in the NNE quadrant.

Anaconda Area

The Anaconda area also has two surface drainage wind systems, one to the west (West Valley) and the other to the southwest (Mill Creek Valley) of the Air Quality Bureau's Highway Junction meteorological monitoring site. Data from the site show surface winds are most prevalent from the WSW quadrant. A comparison of early morning and afternoon surface winds indicates a predominance shift during the day from westerly to southerly, most noticeable in the summer months. A comparison of summer and autumn data taken in the morning indicates a change from a westerly to a northerly predominance over the seasons. Afternoon data show the reverse with a switch from northerly to westerly. Calm conditions were experienced only during November and December. The average wind speed appears to be constant from month to month and season to season. The highest average winds were from SSW-WSW, the greatest during the afternoon observations. The maximum monthly average was 8.0 meters per second (m/sec) from the SW in December. The lightest winds observed were from the N quadrant.

Review of the wind distribution aloft for Anaconda indicates that the predominant winds in the lower 300 meters are from the SSW-W. This situation holds relatively constant month to month and season to season for both morning and afternoon measurements. Average wind

speeds aloft were understandably higher than at the surface, the highest occurring from the W quadrant. The lightest winds were from the East quadrant. Above 300 meters the distribution pattern changes. With increasing altitude the predominant winds increasingly shift to a more northerly direction so that in the extreme upper levels the predominant winds are from WSW-WNW. Average wind speeds at these levels were relatively consistent month to month. The highest winds were from the SW quadrant while the lowest were from the North quadrant.

Kalispell Area

In the Kalispell area the predominant wind at the surface was from the north quadrant in the morning, switching around to southerly in the afternoon. This switch was most noticeable in the early fall. During the colder months the direction change was much less. The surface wind speeds also changed noticeably from morning to afternoon. The mornings had the lightest wind with averages around 1 m/sec. During the afternoons this had picked up to about 4 m/sec.

The Kalispell upper level winds showed a much different pattern than at the surface. At about 500 meters above ground the winds in the morning and afternoon were much more southerly. No clear shift of direction from morning to afternoon was evident. The difference in the morning winds from the surface to 500 meters demonstrated a marked directional variation from a N-NNE direction at the surface to a S-SSW direction at 500 meters.

Billings Area

In general, the Billings area data shows a prevailing surface wind from the SW during all months reviewed. Prevailing winds aloft

were from the WSW-W up to 1000 meters and from W-NW at levels above 1000 meters. These values varied little from month to month. Surface wind speeds were lower in the morning, averaging 0.5-6.0 m/sec, than in the afternoon, when they ave-aged 1.7-6.4 m/sec. A definite seasonal variation is apparent in Billings with wind speeds greater in fall and winter than in summer. Wind speeds increased with altitude, becoming 3-5 times greater at 1500 meters than at the surface.

Missoula Area

In the Missoula area upper level wind measurements are taken at two locations, the USFS Fire Lab northwest of Missoula, and at Lion's Park in Missoula. At the Fire Lab site the data has shown a surface flow mainly from the WNW-N during the spring and summer. During the autumn this flow changed to a more southerly predominance during the mornings and more westerly during the afternoons. Average speeds are less than 5 m/sec during the spring and summer to slightly higher during the fall season. The upper level winds are predominantly westerly except mornings during the summer when the flow is from the SE.

Upper level wind measurements taken during the autumn at the Lion's Park are much the same as those taken at the Fire Lab. The only difference shown between the two sites is the more westerly low level morning flow at Lion's Park Site. Further analysis will determine whether the difference is due to the topography of the Missoula valley.

Afternoon soundings at Lion's Park show a surface flow of Sw-W at less than 5 m/sec with a more west-northwesterly upper level flow.

Detailed analyses of the surface and upper level flows in the Missoula valley have begun to describe the wind flow at the surface and

levels up to 1500 meters above the ground, information which previously could only be guessed at. After further analysis this data will prove crucial to simulation modeling of the study cities or to correlations of air pollution levels with emissions of air pollutants. When complete, the data will be put into a readily usable form.

Inversion Study

The atmospheric temperature inversion is probably the most significant meteorological phenomena associated with high air pollution levels, although the presence of an inversion does not always result in high air pollution concentrations. When an inversion does trap pollutants, the height and strength of the inversion are probably the most important determinant of whether high air pollution concentrations will occur at ground level.

The term "inversion" describes a situation where temperatures in the upper air are higher than in lower layers. Normally temperature decreases with height above the ground at a rate of one degree Centigrade for every 100 meters (deg C/100m) elevation. This temperaure change is called the "lapse rate." Occurrence such as the descent of large air masses or heating and cooling of the ground cause variations in the rate of atmospheric temperature changes, sometimes resulting in inversions. Inversions can start at the ground or be hundreds of meters above the ground. Inversions can range in thickness from less than 50 meters thick to more than 500 meters. The intensity measured as the rate of temperature change with height can also vary. There can also be multiple inversions at different heights.

Inversions contribute to air pollution concentrations by trapping pollutants in still air. The presence of still air over an extended

period leads to the concentration of air pollutants near their source until the inversion breaks or rises enough to allow dispersion. If air pollutants are emitted from a tall smokestack above an inversion, the pollution often will remain above the inversion and be carried far downwind by the upper level winds. In Montana, the inversion situation is complicated by mountainous valleys. If an inversion forms over a valley, the air pollutants become trapped within the "box" formed by the valley walls and the inversion which acts as a lid.

A term often associated with inversions but not necessarily related to inversions is the mixing height. Put simply, the mixing height is the height above the ground to which air pollution is readily mixed with air. This height can vary from zero during a surface based inversion to thousands of meters during a clear hot summer afternoon.

The MAPS evaluated many inversion characteristics relating to air pollution, including inversion strength, height, thickness, duration, formation time, breakup time, and rate of the inversion rise. It is very important to determine the frequency, timing and character of these variables for each study area. The limited amount of data available as of January 1, 1979, has been reviewed for this report.

Butte Area

In the mornings the most common mixing heights in the Butte area were from 0-100 meters, during the four months analyzed. However, all months experienced maximum mixing heights up to at least 750 meters. A review of data indicates that mixing heights tended to become greater in the colder months of November and December. Likewise, due to the evolution of greater mixing heights and the higher wind speeds in the mixed layer, the average wind speeds through the mixed layer also

increased through November and December. The afternoon mixing heights in September and October were greater than in the morning, with heights above 1000 meters most common in the afternoon. November and December had mixing heights up to 1500 meters but almost half were less than 250 meters. This indicates very intense but shallow diurnal inversions occur in this valley, caused by daily temperature changes of the ground surface and lower air layers. Although the average afternoon wind speeds through the mixed layer are greater than those in the morning for all months, they decrease from September to November.

Inversions were categorized according to their base height and thickness. Also, they were each assigned a Holzworth strength classification 1 through 5, 1 being the weakest and 5 being the strongest and most intense (see Table 4). Morning inversions were most commonly surface based. The second most common base height was 1000 to 2000 meters. Inversion thickness ranged from 1-750 meters but only a few were over 500 meters. They were mainly Holzworth type 1 or 3. There was little variation in base height, thickness or type from month to month. There were very few surface based afternoon inversions, except during November and December (6.0 percent). Most base heights were greater than 250 meters. The afternoon trend showed base heights decreasing as monthly temperature decreased. Afternoon inversion thickness ranged from 1-250 meters with a few up to 500 meters. Half (50.1 percent) were Holzworth type 1 with 45.1 percent either type 2 or 3. Inversion strengths were found to be relatively constant throughout the day in November and December.

Surface based morning inversions were present 88.3 percent of the days during months recorded. Afternoon inversions were present 8.3 percent

TABLE 4

Holzworth Lapse Rate Categories (Modified)
Values in deg C/100m

Non-Inversion Class	Lapse Rate	Description
1	< -1.60	Very Superadiabatic
2	-1.21 to -1.60	Superadiabatic
3	-0.81 to -1.20	Near Dry Adiabatic
4	-0.41 to -0.80	Near Standard Atmosphere
5	0.00 to -0.40	Weak Lapse

Inversion Class	Lapse Rate	Description
1	0.00 to +0.47	Weak Inversion
2	+0.48 to +1.14	Moderate Inversion
3	+1.15 to +2.82	Strong Inversion
4	+2.83 to +6.00	Very Strong Inversion
5	> +6.00	Extreme Inversion

(Holzworth, 19/4)

of the time. The average lapse rate in the morning inversion was stronger than in the afternoon inversions (2.3 deg C/100 meters vs. 1.0 deg C/100 meters) for the inversion nearest the surface.

Acoustic radar data analysis provided information on inversion frequencies. Most inversions were surface based. During August most inversions were 100-300 meters thick but a continuing trend indicated that by December inversions 300-500 meters thick were nearly as frequent as those 100-300 meters thick. Daily inversion analysis was broken into six-hour blocks beginning at 0000 MST. Inversions did not occur in the 1201-1800 MST block until October. In summary the lowest inversions present at any given time were all surface based but increased in thickness and number as the colder months approached.

Lapse rate data from the KXLF television tower in Butte were compared with temperature sounding data to determine whether the tower data was usable for evaluating atmospheric stability. Data collected so far exhibit similar tendencies but direct comparisons are not as good as desired. Additional data acquisition and analysis will be needed. There are several factors which can account for discrepancies in the comparisons, including terrain influence on temperature and ascent rates (pibal) and distance separation between the soundings and the tower instrument.

Anaconda Area

In the mornings in the Anaconda area the most common mixing heights were from 0-100 meters. Most of the mixing heights for all months were from 0-250 meters.

A brief review of the Anaconda data indicates that the mixing heights tended to become greater in the colder months - November and December. Likewise, due to the greater mixing heights and the consequent higher wind speeds, the average wind speeds through the mixed layers also increased from August, 1978 to December, 1978. In the afternoons the mixing heights were much greater than in the morning, with the most common height being greater than 1000 meters. In the fall, the majority of morning mixing heights were from 0-250 meters while the afternoon majorities were greater than 750 meters. The average wind speed through the mixed layer in the fall was also greater in the afternoon than in the morning.

Morning inversions were most commonly surface based (although not a majority) with thickness' ranging from 1-500 meters, but with only a

few over 250 meters. They were mainly Holzworth type 2 or 3. Neither base height thickness or type tended to vary from month to month. There were very few surface based afternoon inversions, most base heights being greater than 250 meters, with the exception of the colder months (November and December, 1978). The trend was for decreasing base heights with decreasing monthly temperatures. Afternoon inversion thickness ranged from 1-500 meters, with only a few over 250. These are mainly Holzworth type 1 or 2 (weaker than the morning inversions).

Surface based inversions were present on 81.0 percent of the mornings over all the months, compared to 8.8 percent in the afternoon. The average lapse rate in the morning inversion was greater than in the afternoon (1.3 deg C/100 meters vs. 0.6 deg C/100 meters).

A comparison study of lapse rate values of those taken from the temperature soundings and of lapse rates derived from a difference of the surface temperature and the temperature derived from an Anaconda Company sensor located on C-Hill is being conducted to determine the representativeness of the C-Hill values for future stability indexing purposes. Data collected this far (August, 1978, to January, 1979) indicates relatively good lapse rate and temperature comparisons with the exception of November, 1978.

Kalispell Area

In the Flathead Valley an upper air sampling site was established north of Kalispell at Glacier International Airport, which is located in a low part of the valley. As expected, and as indicated by the data, inversions were found to be formed during most nights from 1800 to 0600 MST. During the 12-hour period from 1800 to 0600 MST, it was

found for the months of July, August and October that inversions were present 93 percent of the time. All of these were surface based except for one in August. Inversions were present 77 percent of the time during the same hours of November. All were surface based except two. For the hours 0600 to 1200 MST inversions were present 59 percent of the time in July and August. Only 20 percent of these were surface based. Inversions were present 67 percent of the time over the same hours in October and November. Ninety-six percent of these were surface based. The lower incidence of surface based inversions in July and August reflects the influence of longer days and additional heating at the surface during the morning hours. Inversions were almost nonexistent during the afternoon period from 1200 to 1800 MST in July and August. Only two were observed in July and both of these were fairly high. Afternoon inversions were more common in the autumn months, with five occurring in October and three in November. All of these were elevated inversions except for one in November.

All elevated inversions were found to be about 100 meters thick in all months. Surface based inversions were found to be thicker in the autumn months of October and November as compared to the summer months of July and August.

Billings Area

In the mornings in the Billings area, surface based inversions from 100-250 meters thick were most common and accounted for 25-30 percent of all inversions. These inversions were generally of Holzworth types 2 or 3. The frequency of this type of inversion did not vary greatly from month to month. Elevated inversions were generally thinner and weaker than surface based inversions. The elevated inversions were

mostly less than 100 meters thick and of Holzworth type 1.

During the afternoons there were no surface based inversions, except in December. About 50 percent of the afternoons had no inversions at all. During afternoons when inversions occurred, they were usually elevated, less than 100 meters thick and of Holzworth type 1.

In the mornings mixing heights were mostly less than 250 meters and did not appear to vary much from month to month. The average wind speed through the mixed layer was lowest in August and highest in December. In the afternoons, the mixing heights were greater than 1000 meters about 40 percent of the time and less than 250 meters another 40 percent of the time. The frequency of low afternoon mixing heights is greater than would normally be expected and is probably due to the abnormally cool, cloudy weather experienced during the latter half of 1978. The wind speed through the mixed layer was higher in the afternoons than in the mornings, and was least during August and greatest in November.

Frequency tables of lowest and second lowest inversions also were derived from acoustic radar records. Data from the months of September through November were available for this report. Inversion data from the radar show that during the night time hours (1800-0600 MST) surface based inversions from 100-300 meters thick were most common, occurring 40 percent of the time in September and 67 percent of the time in October. The increase in October is due to the greater occurrence of inversions in the pre-midnight hours compared to September. During both months the frequency of inversions was greatest between midnight and 0600 MST

and least between 1201 and 1800 MST, when there were no inversions noted during either month. Elevated first inversions were uncommon during both months, occurring less than 15 percent of the time. Those that did occur were mostly less than 100 meters thick and all had bases less than 400 meters above ground level. During both months, these inversions were most common from 0600-1200 MST, and were probably surface based inversions lifted off the ground by warming.

Presence of more than one inversion at a time was very uncommon, occurring only two percent of the time in September and six percent in October. Without exception, the second inversions occurred after midnight and before noon, and were most common between midnight and 0600 MST in September and between 0600 and 1200 MST in October.

Missoula Area

Most inversions (80 percent) in the Missoula area were surface based and most occur during the two six-hour periods from 1800 MST to 0600 MST. They are formed as a result of the typical night time radiational cooling at the surface. Nearly all are less than 500 meters thick and 65 percent of the total are 300 meters or less. Of the total number of six-hour periods, a surface based inversion existed during 40 percent of the periods in June 1978 (the lowest monthly percentage) and 54 percent in November 1978 (the highest percentage).

Inversions on summer mornings (June-August) in Missoula usually have higher base heights (250-500 meters) and are thinner (1-100 meters) than on autumn mornings (September-November). Inversions on autumn mornings are slightly stronger than those of summer mornings.

Inversions on summer afternoons are almost 1000 meters higher than those in the autumn. Summer afternoon inversions are mostly 1-100 meters thick, whereas autumn afternoon inversions are 1-250 meters thick. As is true with the morning inversions, autumn afternoon inversions are slightly stronger than summer afternoon inversions.

During the summer season morning mixing heights of 100-250 meters are most common. During the autumn season morning mixing heights are most common from the surface to 100 meters. The most common mixing heights for summer afternoons in Missoula are greater than 1500 meters, whereas for the autumn season the afternoon mixing heights occur mainly from 250-500 meters.

Analysis was made in Missoula of average composites per month at several levels from the surface to 2100 meters of the upper level temperatures. In all, morning months except September show an atmosphere which warms from the surface to an average of 600 meters and then cools from 600 meters on up. The month of September shows constant temperature from the surface to 160 meters, with progressive cooling with greater heights.

The average height that the temperature warms is higher (700 meters) for the autumn season (October, November) than for the summer season (July, August-500 meters).

In the afternoon atmosphere all months except November show a normal atmosphere in cooling from the surface upward. November shows constant temperature from 160-430 meters and then a normal cooling upward.

A temperature lapse rate was computed from the surface temperature measured at the National Weather Service in Missoula and the 1121 meter temperature measured by KECI-TV atop TV Mountain. Comparisons were

then made between this lapse rate and the lapse rate measured by the temperature sounding conducted at the upper air site northwest of Missoula.

The first comparison made was for days that pilot balloons were released (Monday, Wednesday and Friday, weather permitting). The morning releases (1/2 hour after sunrise) on these days show an overall agreement between the two lapse rates of 68 percent of 54 total cases. The month of September shows the best agreement of 90 percent of 10 total cases. The afternoon releases (1400 MST) show an overall agreement between the two lapse rates of 52 percent of 46 total cases. The month of November shows the best agreement of 80 percent of 10 total cases.

In the mornings the temperature sounding lapse rate showed a stronger inversion lapse rate than the NWS/KECI temperature lapse rate. In the afternoons the temperature sounding lapse rate was a stronger lapse rate (greater decrease in temperature) as compared to the NWS/KECI temperature lapse rate.

The second comparison made was of total lapse rates for each month instead of individual days (cases). The NWS/DECI morning (0500 or 0800 MST) temperature lapse rates were mainly a Holzworth non-inversion Class 3 (219 total cases). The temperature sounding morning (1/2 hour after sunrise) temperature lapse rates were mainly a Holzworth inversion Class 1 (58 total cases).

The NWS/DECI afternoon (1400 MST) temperature lapse rate were generally a Holzworth non-inversion 3 Class (235 total cases). The temperature sounding afternoon (1400 MST) temperature lapse rate were Holzworth non-inversion Class 2 (58 total cases).

The temperature lapse rate computed from NWS/KECI temperatures is very general. Computations will not show an inversion whose ceiling height may be less than 1121 meters or an inversion whose base is greater than 1121 meters.

The temperature lapse rates compared are measured with different instruments and exposures. The height of T-sonde is computed assuming a constant ascent rate for the pilot balloon. Due to atmospheric conditions (wind, precipitation, etc.) the meteorological balloon may carry the temperature sonde several miles away from TV Mountain and to a height more or less than 1121 meters. The morning comparisons are made at 0500 MST or 0800 MST for NWS/KECI lapse rate and 1/2 hour after sunrise for sounding lapse rate. There is a five hour spread in which the morning comparisons are made. These differences may account for some of the disagreement between the two lapse rates.

Further analysis will attempt to determine the conditions under which there would be good agreement between the lapse rates. If this can be established, the mountain top sensors can become an important predictive tool for inversion conditions.

City Comparisons

Analysis was done in all cities of the average time that the surface based inversion formed in the evening and the average time that the inversion lifted off the surface during the morning hours (Table 5). The data when corrected for differences in sunrise times shows no clear indication that inversions form earlier in any city than in any other (Table 6). There is enough variation from city to city and from month to month to obscure any patterns. The average inversion

TABLE 5

Inversion Formation Time (MST)[b]

	May	June	July	August	September	October	November	December
Missoula	1925	2010	1940	1920	1850	1805	1800	IP+
Butte	Data not available at report time							
Anaconda	ND*	2000	1950	2005	1925	1815	1805	1715
Kalispell	1850	ND	1930	1920	ND	1805	1750	1730
Billings	ND	ND	ND	ND	1955	1810	1730	NI[a]
Scobey	1840	1830	1845	1830	1730	1625	1615	1545

*No data
[a]No inversion due to windy conditions
[b]Average time of day when surface based inversion forms
+Persistent inversion

Inversion Lifting Time (MST)[+]

	May	June	July	August	September	October	November	December
Missoula	0735	0630	0635	0750	0805	0835	0925	IP
Butte	Data not available at report time							
Anaconda	ND	0630	0630	0655	0740	0800	0830	1015
Kalispell	0840	ND	0715	0750	ND	0925	0950	1105
Billings	ND	ND	ND	ND	0815	0820	0850	NI
Scobey	0610	0605	0615	0655	0730	0810	0915	IP

[+]Average time of day when surface based inversion lifts off ground

TABLE 6

Inversion Formation Time (MST-Corrected)[b]

	May	June	July	August	September	October	November	December
Missoula	1925	2010	1940	1920	1850	1805	1800	IP[+]
Butte	Data not available at report time							
Anaconda	ND	2005	1955	2010	1930	1820	1810	1720
Kalispell	1850	ND*	1930	1920	ND	1805	1750	1730
Billings	ND	ND	ND	ND	2020	1835	1755	NI[a]
Scobey	1915	1905	1910	1905	1805	1700	1650	IP

*No Data
[+]Persistent inversion
[a]No inversion due to windy conditions
[b]Time corrected due to differences in latitude

Inversion Lifting Time (MST Corrected)

	May	June	July	August	September	October	November	December
Missoula	0735	0630	0635	0750	0805	0835	0925	IP
Butte	Data not available at report time							
Anaconda	ND	0635	0635	0700	0745	0805	0835	1020
Kalispell	0840	ND	0715	0750	ND	0925	0950	1105
Billings	ND	ND	ND	ND	0840	0845	0915	NI
Scobey	0645	0640	0650	0730	0805	0845	0950	IP

Inversion Angle of Ascent[+]

	May	June	July	August	September	October	November	December
Missoula	220	200	236	235	180	160	160	IP
Butte	Data not available at report time							
Anaconda	ND	175	185	170	160	160	130	140
Kalispell	230	ND	250	290	ND	255	245	190
Billings	ND	ND	ND	ND	145	200	155	NI
Scobey	220	240	285	315	320	330	310	IP

[+]Average rate of rise in meters of the surface based inversion as it lifts off the ground based on a two hour or less time period when inversion first lifts

formation time varies from 2000 MST in the summer to 1730 MST in early winter. Often however snow cover in the winter prevented an inversion from breaking up and resulted in the continuation of the inversion for more than one day. In Billings the early winter had such strong winds that few inversions occurred. Differences in lift-off time of inversions from the surface was not clearly discernible from city to city. The average lifting time varied from 0630 MST in the summer to 1000 or 1100 MST in early winter.

The rate at which the inversion lifted off the surface also was analyzed and served as a useful indicator of the amount of time that the surface could be fumigated with high concentrations of air pollutants. A very fast rising inversion would prevent long lasting fumigations.

The preliminary results of this analysis showed inversions generally lifted much more rapidly during the summer than during the early winter. The values varied from about 250 meters rise over a two-hour period during the summer to about 160 meters rise over the same period during the early winter. This would probably be due to the greater amount of solar radiation being received during the summer and the less intense inversions during the same period.

Stability

Stability is probably the least understood meteorological variable by the public. Stability also is one of the areas most often disagreed about by various meteorologists. However, stability is a critical measurement in assessing the meteorology related to air pollution.

Stability is a term that attempts to describe the motions of the atmosphere. It is related most directly to wind and temperature change with height. Generally three relative descriptions of stability are given to the atmosphere. These are unstable, stable, and neutral. Probably the simplest method of relating to each is that in an unstable atmosphere the motions of air are enhanced; in a stable atmosphere the air motions are suppressed; and then a neutral atmosphere is mid-way between stable and unstable. Further breakdowns are given to each describing the degree of stability such as slightly stable or moderately stable.

Stability frequency was determined from the acoustic radar data obtained in Butte, Billings, Missoula and Kalispell (Table 7). Using an initial determination by the field meteorologists from interpretations of the radar record, further breakdowns as to the degree of stability were made using cloud height and cover and wind speeds (Turner, 1970). The stabilities were determined for two-hour periods continuously throughout the months. A large portion of stability data in the Butte area could not be calculated as the stability categories depended on FAA observations which often were missing (Table 8).

In the Missoula area the data shows a fairly normal distribution of the various stability categories for this area. During the summer there are 7-10 percent of moderate to very unstable hours with about twice that many moderately stable hours. The greatest percentage of hours are in the categories of slightly unstable to slightly stable as would be expected. As one approaches the fall, the percentage of moderate and very unstable hours decreases to only 5 percent.

ACOUSTIC RADAR ANALYSIS

Table 7 - MISSOULA

Two-Hour Stability (% Frequency of Occurrence)

Month	A	B	C	D	E	F	U	M
MAY 1978	0.3	1.3	15.3	28.8	21.8	5.4	0.0	27.2
JUNE 1978	3.1	5.8	23.1	30.8	15.6	20.3	0.0	1.4
JULY 1978	3.2	4.3	25.0	23.4	14.0	23.7	0.0	6.5
AUGUST 1978	0.3	2.2	26.3	23.4	22.8	20.2	0.0	4.8
SEPTEMBER 1978	0.0	3.1	20.0	29.4	24.4	16.7	0.0	6.4
OCTOBER 1978	0.0	6.5	19.1	21.8	15.9	36.3	0.0	0.5
NOVEMBER 1978	0.0	5.3	9.2	32.8	41.7	11.1	0.0	0.0

Stability Designation

A - Very Unstable, B - Moderately Unstable, C - Slightly Unstable, D - Neutral, E - Slightly Stable, F - Moderately Stable, U - Unknown, M - Missing Data

KALISPELL

Month	A	B	C	D	E	F	U	M
JULY 1978	.3	2.4	21.5	23.7	11.3	18.8	.8	21.2
AUGUST 1978	0.0	1.3	21.8	32.8	14.5	17.7	.8	11.0
OCTOBER 1978	0.0	3.2	9.4	16.7	15.6	17.7	.3	37.1
NOVEMBER 1978	0.0	3.3	5.3	52.5	29.2	9.7	0.0	0.0

BUTTE

Month	A	B	C	D	E	F	U	M
MAY 1978	0.0	0.5	22.0	32.3	14.5	0.0	0.0	30.6
JUNE 1978	0.0	1.7	29.7	22.5	11.4	0.0	0.0	34.7
JULY 1978	0.0	2.4	23.1	17.2	7.0	0.0	0.0	50.3
AUGUST 1978	0.0	3.0	24.5	22.8	8.1	0.0	0.0	41.7
SEPTEMBER 1978	0.0	1.1	16.4	32.5	8.9	0.0	0.0	41.1
OCTOBER 1978	0.0	1.9	16.7	21.5	10.2	0.0	0.0	49.7
NOVEMBER 1978	0.0	0.3	2.5	37.8	10.6	0.0	0.0	48.9
DECEMBER 1978	0.0	0.0	0.0	33.9	15.9	0.0	0.0	50.3

BILLINGS

Month	A	B	C	D	E	F	U	M
September 1978	0.0	0.3	16.7	33.6	20.6	4.2	0.0	24.7
OCTOBER 1978	0.0	0.3	19.9	33.1	37.9	7.8	0.0	1.1
NOVEMBER 1978	0.0	0.0	4.4	14.7	21.4	0.6	0.0	58.9

TABLE 8

STABILITY CLASSIFICATION FROM ACOUSTIC RADAR CHARTS

Initial Classification	Event Occurring*	Wind Speed	Night-Time	Cloud Cond.	Solar Radiation	Final Classification
Stable	Yes	-	-	-	-	Neutral
	No	$<$3m/sec	Yes	$\leq$3/8	-	Moderately stable
	No	$<$3m/sec	Yes	OVC or $\geq$4/8	-	Slightly stable
	No	$<$5m/sec	Yes	$\leq$3/8	-	Slightly stable
	No	$<$5m/sec	Yes	OVC or $\geq$4/8	-	Neutral
	No	$\geq$5m/sec	Yes	-	-	Neutral
Unstable	Yes	-	-	-	-	Neutral
	No	$<$2				
Neutral	-	-	-	-	-	Neutral

*Event includes precipitation, inversion breakup, or frontal passage.

Consequently the categories slightly unstable to slightly stable increase in percent occurrence during the fall. The areas of Kalispell, Butte, and Billings show basically the same trend; however, less data is available from these areas. At this point in the study it is difficult to show any differences in trends at the various cities due to the small sample available. However, the fall season does show a higher percentage of moderately stable cases west of the continental divide versus east of the divide. This would tend to mean the areas west of the divide would have more stagnant conditions during the fall seasons. Much more analysis will be required of this data prior to any final conclusions.

Turbidity

Atmospheric turbidity is a parameter describing the amount of light scatter or absorption of sunlight due to particles or gases in the atmosphere. Basically as sunlight enters the earth's atmosphere it can be scattered by small dust particles and molecules or it may be absorbed by ozone, water vapor, or other gases. By determining a value for the scattering due to molecules called Rayleigh scattering and a value for absorption by ozone and other gases except water vapor, measurements of various wavelengths can then determine the extinction of sunlight due to dust and water vapor.

The instrument used in MAPS was a hand held sun photometer which measured five wavelengths. One of these wavelengths was centered in the band where water vapor has its greatest effect (940 nm) and one was centered in a wavelength where water vapor has little or no effect

(880 nm). Therefore a determination of the sunlight extinction due to water vapor separate from the extinction due to particles could be made.

Conclusions about the scattering due to different sized particles could also be made with the three remaining wavelengths (440, 500 and 560 nm).

Readings were taken at three predetermined times - 0900, 1200 and 1500 MST. Readings could be taken only if the sun was unobscured by clouds. The results were then tabulated by city, wavelength, and time (Table 9).

Looking first of all at the 940 and 880 nm wavelengths concerning absorption of sunlight by water vapor, the results generally tend to show the areas west of the continental divide have slightly higher turbidities (more extinction) for the 880 nm wavelength than the areas east of the divide. The trend also shows slightly lower values in the late fall and early winter than the early fall. The values are also higher for the 880 nm wavelength during the mid-day than the morning or the evening values. The 940 nm wavelength does not show the same daily trend. The values for the 940 nm channel vary with no distinct trend during the day. However, the 940 nm values do show a similar trend to the 880 nm values for early fall to late fall time periods. No distinct difference of west to east of the divide is apparent for the 940 nm wavelength. This would tend to mean the amount of absorption due to water vapor is fairly constant throughout the state.

Analysis of the three remaining wavelengths of the sun photometer (440, 500 and 640 nm) does not reveal any obvious trend or

TABLE 9

Atmospheric Turbidity Data
Average 0900 MST - 1978
Wavelength 440 nm

	July	August	September	October	November	December
Missoula	ND*	0.23	0.21	0.23	ND	0.09
Butte	ND	0.17	0.16	0.12	0.12	ND
Anaconda	0.38	0.23	ND	0.08	ND	ND
Col. Falls	ND	0.15	0.18	0.14	ND	0.09
Helena	ND	ND	ND	0.14	0.15	ND
Billings	ND	0.20	0.18	0.15	0.38	ND
Scobey	0.19	0.16	0.19	0.11	0.16	0.09

*ND - No data due to instrument problems or weather conditions

Atmospheric Turbidity Data
Average 1200 MST - 1978
Wavelength 440 nm

	July	August	September	October	November	December
Missoula	ND	0.28	0.28	0.23	0.51	0.29
Butte	ND	0.23	0.18	0.17	ND	ND
Anaconda	0.34	0.35	ND	0.26	ND	ND
Col. Falls	ND	0.22	0.19	0.25	0.20	0.20
Helena	ND	ND	0.20	0.19	0.20	ND
Billings	ND	0.25	0.22	0.20	0.21	ND
Scobey	0.23	0.20	0.19	0.16	ND	0.17

Atmospheric Turbidity Data
Average 1500 MST - 1978
Wavelength 440 nm

	July	August	September	October	November	December
Missoula	ND	0.25	0.25	0.20	0.40	0.17
Butte	ND	0.28	ND	0.15	ND	ND
Anaconda	0.34	0.33	ND	0.12	ND	ND
Col. Falls	ND	0.21	0.26	0.22	0.23	0.15
Helena	ND	ND	0.16	0.14	0.14	ND
Billings	ND	0.21	0.21	0.15	0.36	ND
Scobey	0.22	0.18	0.15	ND	0.11	0.11

Atmospheric Turbidity Data
Average 0900 MST - 1978
Wavelength 500 nm

	July	August	September	October	November	December
Missoula	ND	0.13	0.13	0.17	ND	0.04
Butte	ND	0.09	0.09	0.07	0.07	ND
Anaconda	0.22	0.14	ND	0.06	ND	ND
Col. Falls	ND	0.07	0.13	0.08	ND	0.07
Helena	ND	ND	ND	0.08	0.10	ND
Billings	ND	0.12	0.09	0.08	0.10	ND
Scobey	0.09	0.07	0.09	0.06	0.06	0.02

Atmospheric Turbidity Data
Average 1200 MST - 1978
Wavelength 500 nm

	July	August	September	October	November	December
Missoula	ND	0.17	0.19	0.13	0.34	0.16
Butte	ND	0.13	0.11	0.10	ND	ND
Anaconda	0.22	0.22	ND	0.21	ND	ND
Col. Falls	ND	0.11	0.09	0.16	0.17	0.15
Helena	ND	ND	0.11	0.11	0.13	ND
Billings	ND	0.15	0.13	0.10	0.12	ND
Scobey	0.10	0.08	0.11	0.10	ND	0.06

Atmospheric Turbidity Data
Average 1500 MST - 1978
Wavelength 500 nm

	July	August	September	October	November	December
Missoula	ND	0.14	0.17	0.12	0.26	0.09
Butte	ND	0.16	ND	0.10	ND	ND
Anaconda	0.20	0.20	ND	0.08	ND	ND
Col. Falls	ND	0.11	0.15	0.13	0.16	0.09
Helena	ND	ND	0.09	0.09	0.09	ND
Billings	ND	0.11	0.12	0.08	0.08	ND
Scobey	0.11	0.08	0.08	ND	0.04	0.05

Atmospheric Turbidity Data
Average 0900 MST - 1978
Wavelength 640 nm

	July	August	September	October	November	December
Missoula	ND	0.09	0.07	0.13	ND	0.04
Butte	ND	0.05	0.04	0.03	0.04	ND
Anaconda	0.12	0.07	ND	0.03	ND	ND
Col. Falls	ND	0.05	0.09	0.06	ND	0.07
Helena	ND	ND	ND	0.04	0.06	ND
Billings	ND	0.11	0.07	0.08	0.10	ND
Scobey	0.05	0.04	0.05	0.04	0.04	0.03

Atmospheric Turbidity Data
Average 1200 MST - 1978
Wavelength 640 nm

	July	August	September	October	November	December
Missoula	ND	0.11	0.16	0.08	0.23	0.11
Butte	ND	0.07	0.04	0.03	ND	ND
Anaconda	0.10	0.11	ND	0.12	ND	ND
Col. Falls	ND	0.06	0.05	0.11	0.13	0.13
Helena	ND	ND	0.05	0.05	0.07	ND
Billings	ND	0.10	0.11	0.07	0.18	ND
Scobey	0.06	0.04	0.08	0.06	ND	0.02

Atmospheric Turbidity Data
Average 1500 MST - 1978
Wavelength 640 nm

	July	August	September	October	November	December
Missoula	ND	0.10	0.13	0.08	0.20	0.07
Butte	ND	0.10	ND	0.04	ND	ND
Anaconda	0.11	0.09	ND	0.04	ND	ND
Col. Falls	ND	0.07	0.11	0.09	0.12	0.08
Helena	ND	ND	0.05	0.05	0.05	ND
Billings	ND	0.08	0.09	0.07	0.07	ND
Scobey	0.07	0.04	0.06	ND	0.03	0.04

Atmospheric Turbidity Data
Average 0900 MST - 1978
Wavelength 880 nm

	July	August	September	October	November	December
Missoula	ND	0.07	0.05	0.11	ND	0.05
Butte	ND	0.06	0.05	0.03	0.04	ND
Anaconda	0.09	0.06	ND	0.04	ND	ND
Col. Falls	ND	0.05	0.09	0.04	ND	0.05
Helena	ND	ND	ND	0.04	0.05	ND
Billings	ND	0.07	0.05	0.05	0.05	ND
Scobey	0.04	0.04	0.06	0.03	0.03	0.02

Atmospheric Turbidity Data
Average 1200 MST - 1978
Wavelength 880 nm

	July	August	September	October	November	December
Missoula	ND	0.09	0.06	0.06	0.19	0.08
Butte	ND	0.08	0.06	0.05	ND	ND
Anaconda	0.10	0.10	ND	0.14	ND	ND
Col. Falls	ND	0.07	0.05	0.09	0.11	0.09
Helena	ND	ND	0.06	0.06	0.07	ND
Billings	ND	0.06	0.08	0.05	0.05	ND
Scobey	0.05	0.04	0.07	0.05	ND	0.02

Atmospheric Turbidity Data
Average 1500 MST - 1978
Wavelength 880 nm

	July	August	September	October	November	December
Missoula	ND	0.06	0.12	0.06	0.16	0.05
Butte	ND	0.09	ND	0.04	ND	ND
Anaconda	0.08	0.06	ND	0.04	ND	ND
Col. Falls	ND	0.07	0.09	0.07	0.08	0.04
Helena	ND	ND	0.05	0.05	0.05	ND
Billings	ND	0.06	0.06	0.04	0.04	ND
Scobey	0.06	0.05	0.05	ND	0.04	0.02

Atmospheric Turbidity Data
Average 0900 MST - 1978
Wavelength 940 nm

	July	August	September	October	November	December
Missoula	ND	0.38	0.31	0.28	ND	0.14
Butte	ND	0.24	0.22	0.11	0.10	ND
Anaconda	0.38	0.26	ND	0.09	ND	ND
Col. Falls	ND	0.35	0.32	0.22	ND	0.08
Helena	ND	ND	ND	0.28	0.24	ND
Billings	ND	0.34	0.33	0.22	0.19	ND
Scobey	0.42	0.35	0.45	0.15	0.12	0.05

Atmospheric Turbidity Data
Average 1200 MST - 1978
Wavelength 940 nm

	July	August	September	October	November	December
Missoula	ND	0.40	0.33	0.23	0.21	0.19
Butte	ND	0.25	0.25	0.16	ND	ND
Anaconda	0.37	0.26	ND	0.21	ND	ND
Col. Falls	ND	0.37	0.34	0.28	0.21	0.14
Helena	ND	ND	0.51	0.35	0.30	ND
Billings	ND	0.37	0.41	0.24	0.21	ND
Scobey	0.47	0.36	0.39	0.16	ND	0.06

Atmospheric Turbidity Data
Average 1500 MST - 1978
Wavelength 940 nm

	July	August	September	October	November	December
Missoula	ND	0.35	0.39	0.26	0.21	0.15
Butte	ND	0.31	ND	0.12	ND	ND
Anaconda	0.38	0.28	ND	0.09	ND	ND
Col. Falls	ND	0.37	0.45	0.30	0.22	0.08
Helena	ND	ND	0.47	0.30	0.32	ND
Billings	ND	0.36	0.37	0.26	0.17	ND
Scobey	0.52	0.39	0.33	ND	0.05	0.08

difference between study areas. Values are highly variable with one city having high values one month and low values the next month. With the limited sample available to date and only a brief review of that data, no one city appears to experience turbidities significantly higher on the average than any other city. A much more detailed analysis will have to be made to correlate turbidities with visibility, particulate concentration, meteorological variable, and other related data.

Other Meteorological Parameters Measured

A variety of other meteorological parameters are either being measured under MAPS or are being collected from other sources such as the National Weather Service. These parameters are not summarized in this report, as either their relation to air pollution meteorology is not as important or the variables were used in deriving other parameters discussed in this report and are not important when discussed alone. Also some of the data collected are critical to correlations with the health effects studies and will be discussed in those individual analyses. All of the data collected from the meteorological studies was stored on the new data system developed under MAPS allowing quick and timely retrieval and summary of the data for future analyses. This includes the upper air data as well as the various surface meteorological data.

IV. SUMMARY

A brief analysis of the meteorological data collected under MAPS and other coincident studies has been made. Analyses are far from complete, with more in-depth analysis to be presented in the final report due in June, 1979. This report is designed to detail the methodology being used in the study and reveal the initial results being obtained.

Data on the upper level winds in the various study areas has already revealed predominant wind patterns for the various months sampled. Inversion data from two measurement methods is being summarized and comparisons are being made as to frequency of occurrence of various months sampled. Inversion data from two measurement methods is being summarized and comparisons are being made as to frequency of occurrence of various inversion parameters such as thickness, height, intensity, and duration. Stability data derived from acoustic radar data, cloud data, and wind speed is also currently being tabulated continuously in two-hour periods. Finally data on atmospheric turbidity is being correlated with various air quality and meteorology parameters. Additional data on surface wind patterns, pressure, solar radiation, dewpoint, temperature, etc., are not available at this time but are being sampled continuously and will be analyzed prior to the final report.

REFERENCES

Holzworth, G. C., 1974: Climatological Data on Atmospheric Stability in the United States. American Meteorological Soc. Sym. on Atmos. Diff. and Air Pollution.

Montana Department of Health and Environmental Sciences, 1979: MAPS Approach and Methodology Report. Air Quality Bureau, Helena, Montana.

Super, A. B., et al., 1972: Atmospheric Water Resources Management Program, Final Report Part I. Montana State University, Bozeman, Montana.

Turner, D.B., 1970: Workbook of Atmospheric Dispersion Estimates. Environmental Protection Agency, Research Triangle Park, North Carolina.